

MONITORING MOBILE ROOF SUPPORTS

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ABSTRACT

Researchers from the Spokane Research Center conducted a field study to assess the safety of remotely controlled mobile roof supports (MRS's) in a retreat pillar mining operation. Data were collected to provide the Mine Safety and Health Administration with criteria needed to develop guidelines for MRS use and to determine if precursors could be identified that would alert miners to imminent roof falls.

Two test sites at which two different support methods—MRS's and posts—were used were monitored to obtain information on entry stability. Pressure transducers and string potentiometers were installed on all four MRS's to obtain loading and displacement information. Roof bolt load cells, sonic probes, extensometers, and survey targets were installed in the surrounding entries to obtain information on ground behavior.

Results showed a larger increase in roof bolt loading and roof movement when MRS's were used, especially in the intersection area. Roof bolt loads in the entries showed decreases when the MRS's were set and increases of up to 11.1 kN (2,500 lbf) when the MRS's were unloaded. Unloading of one MRS in a pair did not significantly increase load on the other. MRS's 1 and 2 usually had the higher loads; these loads increased as the pillars on each side were being mined. MRS 3 normally had lower loads than 1 and 2; however, it also experienced some very high loads when in the last position near the pushout. MRS 4 usually had the lowest loads, primarily because it was located near the solid pillar that was not being mined.

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INTRODUCTION

Mobile roof supports (MRS's) (figure 1), also known as breaker line supports, were developed by the former U.S. Bureau of Mines (USBM) in the 1980's [Thompson and Frederick 1986]. Currently, 2 mining equipment companies manufacture commercial units, and 21 units (4 machines per unit) are in operation in U.S. coal mines. MRS's have been in use in Australia since 1987 [Follington et al. 1992], where they replace posts during full or partial pillar extraction.

MRS's were developed to reduce the high number of injuries and fatalities in retreat pillar mining operations [Chase and Mark 1993]. Most of these accidents occur during the preparation and installation of the required turn and breaker posts used in retreat sections.

The Mine Safety and Health Administration (MSHA) is assessing safety associated with the use of MRS's and has asked us for assistance in establishing guidelines for their use.

There is also a need for a method to detect imminent roof failure. Previous methods of using loading on posts and other indicators are no longer applicable when using MRS's.

Use of MRS's requires an understanding of how an active roof support behaves. To further this understanding, the Spokane Research Center conducted a field test in which instruments were installed on four MRS's and in entries surrounding two pillars. One pillar was mined using posts; the other, using an MRS as the support. These instruments included load cells on point-anchor bolts and fully grouted bolts to measure loading and unloading of roof bolt supports, sonic probes to measure displacement in the roof to a depth of 6 m (20 ft), and extensometers and survey targets to measure roof sag. Instruments installed on the MRS's included pressure transducers on all hydraulic lines to measure load on each of the support cylinders and string potentiometers to measure leg closure.

MINE LAYOUT

The field test was conducted at a mine in southwestern West Virginia, where the Lower Cedar Grove Coalbed is being mined. This seam is approximately 2.8 m (10 ft) thick. The Upper Cedar Grove Seam lies 24 to 30 m (80 to 100 ft)

directly above the Lower Cedar Grove Seam, and the Hershaw Seam lies 91 m (300 ft) above. The depth of cover varies from approximately 91 m (300 ft) near the outcrop to over 305 m (1,000 ft).



Figure 1.—Mobile roof supports in operation.

The pillars for the retreat section were developed on 21- by 27-m (70- by 90-ft) centers and 6-m (20-ft) wide entries. Normal roof support consisted of 1.2-m (4-ft) mechanically anchored roof bolts on 1.2-m (4-ft) centers. Breaker posts were still required between the gob and the pillar line.

The test site was located in the second panel being mined with MRS's (figure 2). Each row in the panel had seven or eight pillars, but the number varied depending on whether or not the barrier pillar between the second and first panel had been mined. The test pillars were the third ones from the end of the pillar rows.

The immediate roof is a dark gray shale that contains numerous plant fossils. Its high clay content results in a soft, moisture-sensitive rock with poorly bonded bedding planes. The shale grades upward into a moderately hard, strong sandstone located 1 to 2 m (4 to 6 ft) above the opening.

The pillar recovery method used with the MRS's was "Christmas tree" extraction (figure 3A). With posts only, the pillar recovery method was pocket-and-wing (figure 3B).

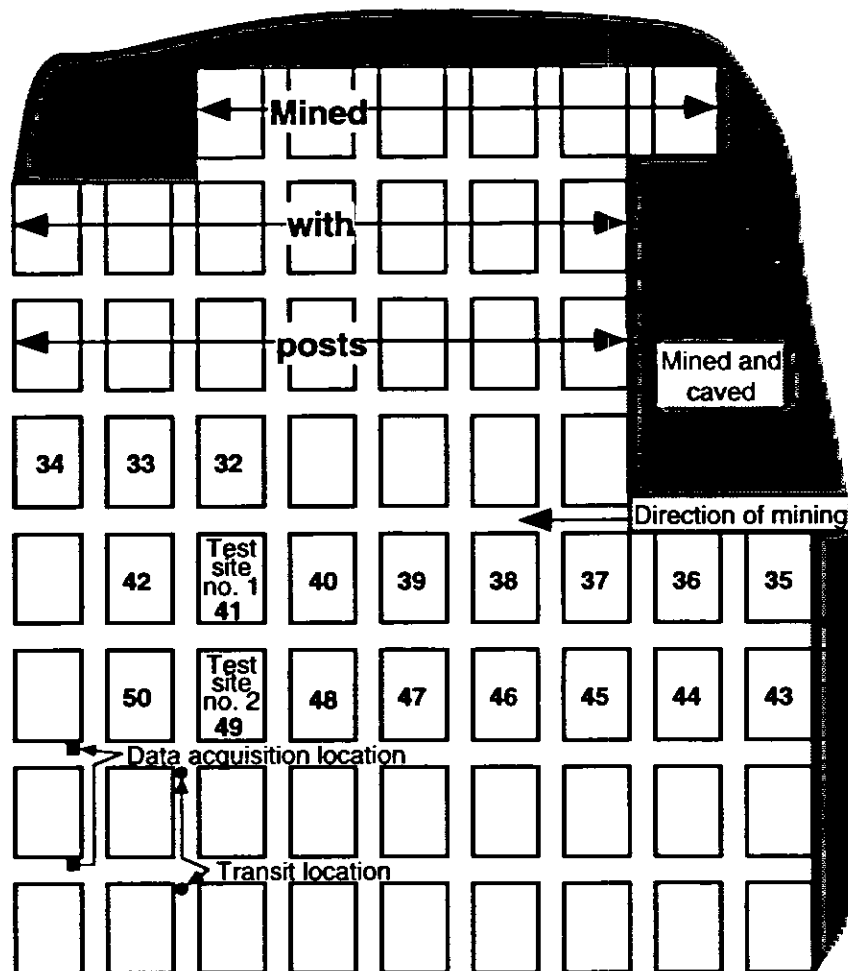


Figure 2.— Retreat panel layout.

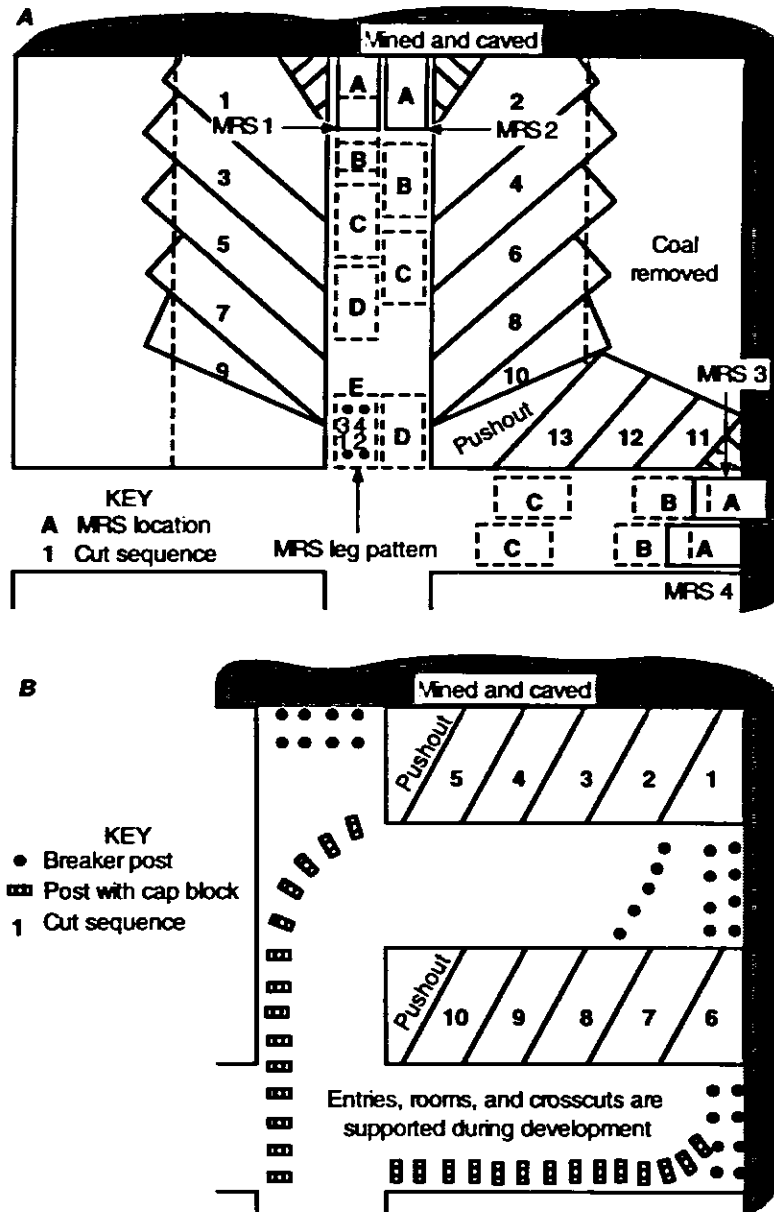


Figure 3.—Mining plan using (A) mobile roof supports and (B) posts.

MOBILE ROOF SUPPORT INSTRUMENTS

HYDRAULIC PRESSURE TRANSDUCERS

Pressure transducers were installed on the hydraulic lines to obtain information on the loading patterns on each of the four support cylinders, as well as on total loading of each MRS. Displacement devices were also installed to measure leg closure. Results showed that the front and rear hydraulic legs were not consistently set to the same loads, but that similar setting loads occurred in the left and right cylinders of the front and rear legs, which were plumbed together. A dial indicator indicated loading on the front pair and the rear pair of leg cylinders, so that the operator could set the desired load for each pair of cylinders.

During pillar mining in the test area, the hydraulic pressures were normally set at 10,000 kPa (1,450 lbf). Shortly after setting each MRS, the load would decrease on each leg. In one case, on MRS 2, it decreased by approximately 80% of the load (figure 4). This decrease could be attributed to bleed-off of hydraulic pressure, soft roof and/or floor conditions, loose debris (coal and rock) on the floor, transfer of load because of mining, or any combination of these conditions. The data show that the decrease in load became less as the MRS was advanced in the entry. Thus, it would be expected that the load decrease resulted from debris on the floor, because that was the only condition that changed.

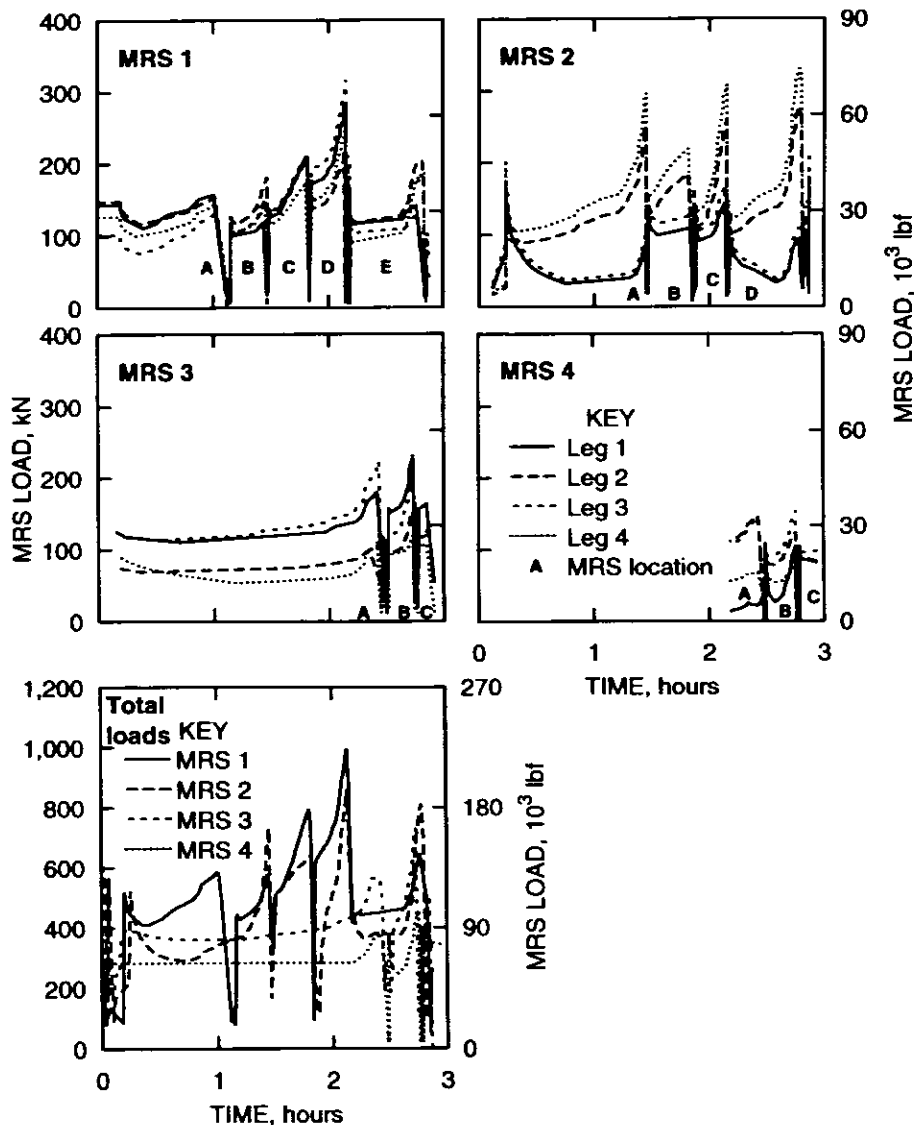


Figure 4.—Loading patterns on mobile roof supports.

The highest loads were attained in the entry with MRS's 1 and 2. Typically, loads on MRS's 1 and 2 increased as mining progressed during a cut and as the pillar size was reduced during successive cuts. The data show that all legs on MRS 1 reached their maximum load at location D in the entry (figure 4). The highest loads were on cylinders 1 and 3, which indicated that loading was greater on the pillar side on the left. On MRS 2, the highest loading occurred at location D in the entry. The highest loads were on cylinders 2 and 4, which were closest to the pillar side on the right. There was no significant increase in loads on MRS's 3 and 4 until the first end cut (6) was being made (figure 3B). The maximum loads on MRS's 3 and 4 were almost the same at both the first and second locations. However, on one occasion, while several other pillars were being mined, MRS 3 exceeded the yield load. The instruments were not collecting data at this time. On MRS 3, the highest loads were on cylinders 1 and 3, which were closest to the pillar being mined. MRS 4 had the lowest overall load of the four MRS's.

To determine if unloading of one MRS increased loading on the MRS next to it, loads were compared when MRS 1 was first moved. The unloading of MRS 1 did not increase the load on MRS 2 (figure 5). In evaluating data during other moves of MRS pairs, there were no significant increases in load on one MRS when another was unloaded.

Data were compiled on the MRS loads for a consecutive 7-day period following the first test to identify maximum loads over an extended time (figure 6). Overall, loading was similar to that found at the first test site. MRS's 1 and 2 had higher maximum total loads than MRS's 3 and 4. However, average total loads on MRS 3 were higher than those on MRS's 1 and 2. MRS 4 continued to take less load than the others.

Monitoring of the MRS's continued during most of the panel mining. One month after the first test, another pillar was observed during extraction and was documented in detail to provide information for an analysis of the MRS data. Loading on each of the MRS's was similar to that at the first test site.

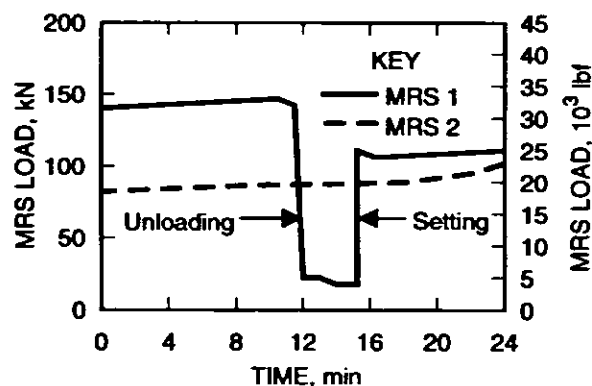


Figure 5.—Effect of MRS 1 unloading on MRS 2.

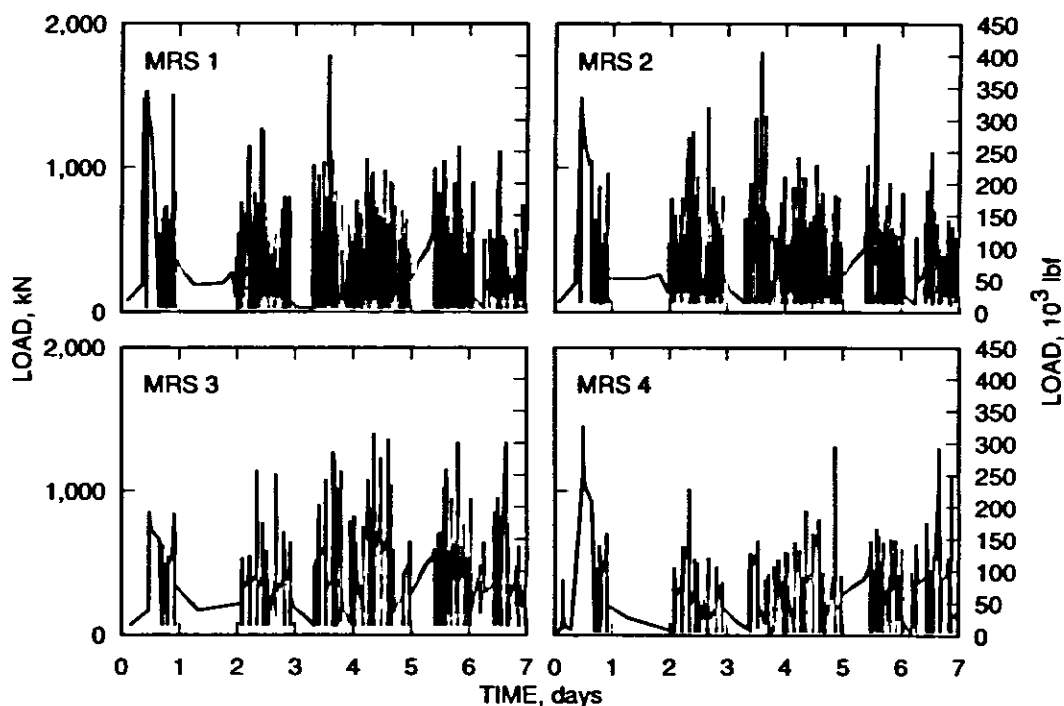


Figure 6.—Total loads on mobile roof supports.

ROOF BOLT LOAD CELLS

Load cells were installed on 1.2-m (4-ft) long, point-anchor roof bolts at 10 locations to determine the impact of MRS setting loads on the roof bolts. These bolts were installed approximately 1 month after normal bolting had been completed. The roof bolts with load cells were centered between existing bolts. Installation tension varied from approximately 25 to 53 kN (5,700 to 12,000 lbf).

These roof bolts were installed in the center of the entry and located between the MRS's at the first MRS set location. During setting of the MRS, the load decreased from about 1.8 to 0.44 kN (400 to 100 lbf) (figure 7). The amount of decrease depended on the position of the MRS's with respect to the position of the roof bolt, the setting load of the MRS at that location, and roof conditions.

During unloading of MRS's 1 and 2 during the first and second moves, load on the roof bolts increased from approximately 1.8 to 3.6 kN (400 to 800 lbf) (figure 8). Similar results were observed when MRS's 3 and 4 were unloaded. This indicates that during unloading, this amount of load was being transferred to the roof bolts. (Note that the monitored roof bolts were installed after the normal bolting cycle; however, it is likely that similar unloading and loading conditions existed on the other roof bolts.) These results confirm that there should be optimum MRS setting loads established that will have the least effect on the existing support and roof strata, yet will still provide adequate support.

The roof bolt load cells showed a significant increase in load when the last lifts were being mined at each test site, from 36 to 48 kN (8,000 to 10,500 lbf) at the MRS site and from 34 to 43 kN (7,500 to 9,500 lbf) at the post site. This increase in load was relative to the load increase on the resin-grouted bolts and roof movement.

ROOF-TO-FLOOR CLOSURE DEVICES (SAGMETERS)

Roof-to-floor closure devices (sagmeters) were installed near the load cells. The purpose was to monitor roof movement and correlate roof-to-floor movement to displacement of the MRS's, as well as to monitor the roof after the MRS's advanced in each of the entries. These readings were then compared with roof movement in the same area when posts had been used.

Results showed a significant amount of closure beginning just prior to moving MRS's 1 and 2 (figure 8) and continuing at a high rate throughout the mining of the pillar. Also, when MRS 1 was moved for the first time, the sagmeters did not show any significant change. This is consistent with figure 5, which shows that the unloading of MRS 1 did not have any effect on the loading of MRS 2. At MRS's 3 and 4, roof response was similar. At the post site, the sagmeters showed a significant rate of movement as the last lift in the first wing was being mined and when mining in the last wing was started.

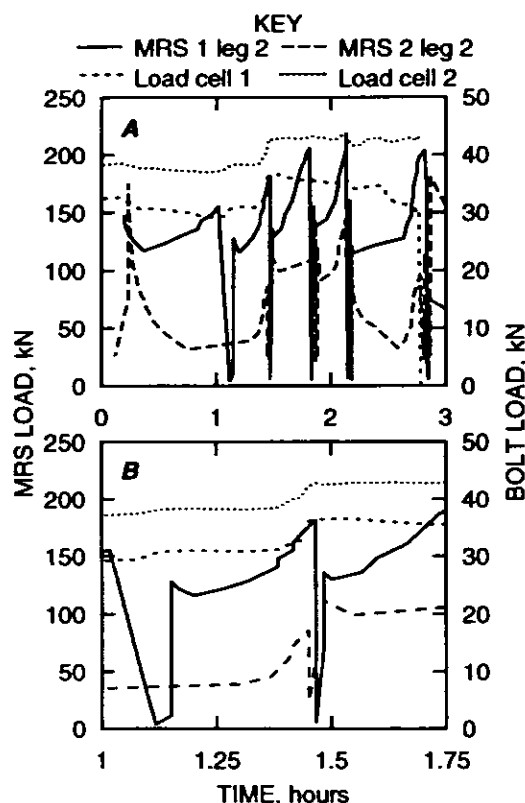


Figure 7.—Loading of MRS 1, MRS 2, and roof bolts for (A) entire pillar and (B) during one cycle.

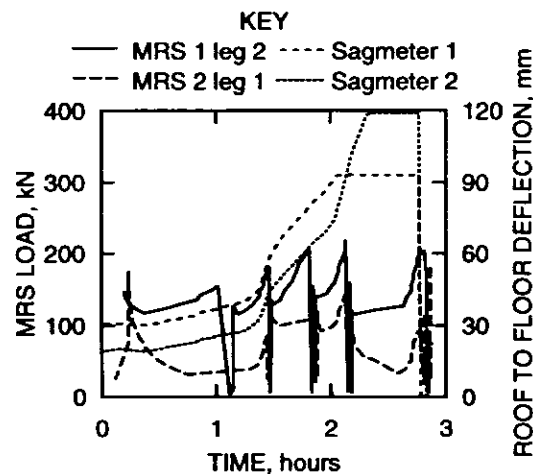


Figure 8.—Loading of MRS 1 and MRS 2, and roof-to-floor closure for entire pillar.

FULL-COLUMN INSTRUMENTED BOLTS

Twelve strain gauges were placed on each of two 1.8-m (6-ft) long, full-column, resin-grouted bolts. One was installed in the center of each of the test site intersections [Signer et al. 1993]. The results showed that strain at both the MRS site and the post site increased rapidly during mining of the last lift (13) and the last wing (10), respectively. Those gauges positioned

135 cm (54 in) above the roof line had exceeded the yield strain. When mining was completed at the test sites, 75% of the strain gauges had exceeded 66% of the yield strain at the MRS site; at the post site, 25% of the strain gauges had exceeded 66% of the yield strain.

SONIC PROBES

Sonic probes were installed to measure roof displacement at increments of 0.3 m (1 ft) to a depth of 6 m (20 ft) above the roof line. One sonic probe was installed in the center of the intersection at each test site. Significantly higher movement was found in the intersection where MRS's were used compared with the intersection where posts were used. Table 1 compares roof movements measured by the sonic probes immediately after the crew completed mining of the pillar and was moving out to the next pillar. There was approximately 4.4 times the amount of movement in the MRS test site, which is consistent with the higher loads recorded on the roof bolts in the intersection area.

Table 1.—Intersection roof displacement

Test site	Movement of roof line with probe end as reference, mm (in)	Maximum separation, mm (in)	Location of maximum separation, mm (in)
Mobile roof support	12.7 (0.500)	3.3 (0.13)	610 (24)
Post	2.9 (0.114)	0.76 (0.03)	914 (36)

SURVEY TARGETS

Survey targets were installed on seven roof bolts and monitored to determine the amount of roof sag in the intersection area at both test sites. From a distance of about 30 m (100 ft), the targets were surveyed with a transit and monitored from the time mining of the pillar was started until mining was completed and miners had left the area. There was only a slight difference between the amount of roof sag at the two sites. The MRS test site showed a slightly higher amount of total roof sag.

SUMMARY AND CONCLUSIONS

1. The location of an MRS is most important during retreat pillar mining. The MRS should be moved as often as possible and kept as close as possible to the continuous miner to reduce the possibility of premature roof caving. It is especially important that the MRS be in the intersection as much as possible to protect miners and equipment, because the results of this test show that the most roof-fall-prone area is the intersection. In this test, the MRS's were not positioned in the intersection.

2. Proper setting loads need to be established to match geologic conditions. It was shown that setting loads were appropriate for the conditions encountered during this test. This conclusion is based on the finding that loads on the roof bolts decreased as the MRS's were set, yet the bolts were still able to support increases in load significantly when the MRS's were released. Other indicators of proper setting loads were that the roof did not break above or around the MRS's and that caving patterns remained the same.

3. There were higher loads on the roof bolts in the intersection area and more roof displacement when MRS's were used. This can be attributed to one or both of the following conditions:

(a) *Type and location of support:* In the MRS test site, MRS's were not positioned in the intersection. In the post test site, posts were installed and left in the intersection.

(b) *Method of mining:* The Christmas tree method was used at the MRS test site, whereas the pocket-and-wing method was used with posts. This may have contributed to some of the difference in roof support loading and displacement.

As stated in item 1 above, the MRS's should be placed into the intersection as much as possible to safeguard miners and equipment.

4. The load loss that occurred immediately after setting the MRS's to the roof can be caused by creep or leaks in the MRS's hydraulic system, soft roof and/or floor conditions, loose coal and rock on the floor, setting pressures that are too high (which causes creep in the roof and floor), or load transfer as a result of mining. A test of the MRS determined that creep was not a significant factor in the MRS system. Of the remaining possibilities, the greatest loss of load would likely be caused by loose coal and rock on the floor, because the loss of load was very rapid immediately after setting. To eliminate this possibility, it is important to clean the floor prior to setting an MRS. This can be done with a continuous miner or the dozer blades on the MRS.

5. A major advantage to using an MRS is that mine personnel no longer need to go into hazardous areas in entries or intersections to install supports as they do when setting posts. Dial gauges are installed on all MRS's to establish setting pressures and to indicate how the MRS's are loading up. Some of this improvement in safety is jeopardized when MRS operators must get close to the MRS to read the dial gauges while they are setting the machine or determining how the MRS's are being loaded. Larger, more visible gauges should be installed to eliminate the necessity of approaching the MRS to read the gauges.

6. Research is continuing to establish optimum setting loads for a variety of conditions, define precursors to roof caving, investigate possible combinations of MRS's and other types of supports, and improve safety when using MRS's.

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APPENDIX.—LOAD RATE MONITORING SYSTEM

Two pressure gauges mounted on each MRS were monitored continually by mine personnel to determine loads and loading rates on the machines. This loading information is used by MRS operators to determine when to cease mining operations and/or remove miners and equipment from an area before a dangerous fall occurs. The dial gauges could be difficult to read, requiring the MRS operator to approach the MRS to monitor the gauges. Spokane Research Center personnel and equipment manufacturers are currently cooperating in the development of a load rate monitoring (warning) system for the MRS. The system monitors dynamic loading on the MRS and activates green, amber, and red warning lights on the canopy near the dial gauges. Each light represents a different loading rate on the machine.

The system uses a dedicated embedded processor to monitor pressure inside the four hydraulic jacks associated with the MRS. Loading is proportional to the internal pressure and the surface area of the piston head of the hydraulic cylinder and is determined by the formula

$$F = A \times P, \quad (A-1)$$

where F = force in pounds,

A = area, in²,

and P = pressure, psi.

The embedded processor reads changes in cylinder pressure through four multiplexed data acquisition channels and converts these pressure changes to load rates, which are then displayed by the three load rate indicator lights.

External components of the load rate monitoring system are shown in the back row in figure A-1. From left to right, the components are pressure transducers and connecting cables for monitoring the internal pressure in the hydraulic cylinders; an explosion-proof, MSHA-approved container that houses the internal components of the system; and three colored fluorescent load rate indicator lights with magnetic mounting bases.

The internal components of the explosion-proof container are shown in the foreground of figure A-1. From left to right, these components are the power supply for the internal components, the embedded processor and associated control program, the solid-state control relays for the lights, and intrinsically safe power supplies and barriers for the external components.

As an integrated package, these components can be retrofitted into existing MRS equipment. Further underground studies of MRS loading histories will be performed to determine critical load rate settings for the system and to evaluate its performance.

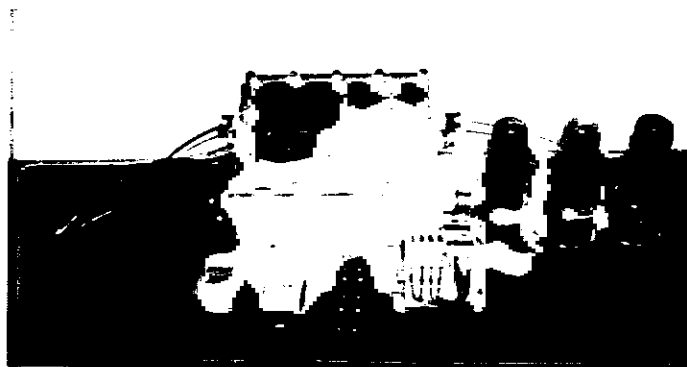


Figure A-1.—Load rate monitoring system components.